U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY

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NOISE SIGNALS AND CARRIER MODULATION ARISING IN ELECTRICAL CABLES DURING NUCLEAR PULSE IRRADIATION

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Abstract

The electrical noise signals generated in the individual conductors of coaxial and other cables by incident nuclear radiation pulses were studied as a function of the applied voltage and the exposure history. Training processes were found to reduce the response signals in repetitive exposures, while storage or memory effects can cause strong readout signals if the applied voltage is changed in successive shots. Oscillatory signals in the center conductor were found to be caused by differentiation of the unexpectedly large shield current pulses. The latter can also inject parasitic leakage currents into other conductors nearby. An RF signal transmitted through RG62 A/U cable suffers a temporary attenuation of almost 20 percent, while it passes through RG59 B/U cable unaffected. Methods for the dynamic measurement of noise, resistance, attenuation and impedance are described, and definite rules are given for minimizing noise signals from cables used in nuclear pulse radiation measurements.

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NOISE SIGNALS AND CARRIER MODULATION ARISING IN ELECTRICAL CABLES DURING NUCLEAR PULSE IRRADIATION

INTRODUCTION

The methods and techniques for dynamically measuring the performance characteristics of electronic parts, devices and circuits during their exposure to nuclear radiation pulses are greatly different from those used for the same purpose in a normal environment. Some methods cannot be used for such measurements at all, because the assumptions on which their operation is based are invalidated by the effects of radiation and almost all others must undergo considerable modification before they can be used in a pulsed nuclear environment. Undesirably long transmission lines between the test object and the measuring instrumentation are usually inevitable because of safety considerations for the operating personnel. While the length of the cables by itself already causes an inevitable loss in sensitivity of the measurements, the noise signals generated in the cable where it is exposed, together with the test object, can render the observed results questionable, useless or even misleading.

The measurements of electronic parts, devices and circuits can not attain the required level of sensitivity, accuracy, and statistical confidence unless these uncertainties are eliminated. Our work was mostly aimed at this goal, and we were able to establish certain rules for the behavior of the cable noise signals and also some semiquantitative limits for the magnitude of their response under the conditions studied.

Besides the noise signals which usually consist of an actual current pulse induced in the cable, the nuclear radiation may also cause changes in insulation resistance and effective capacitance of the cable which affect its transmission characteristics. Such changes may cause amplitude modulation and phase shift in a transmitted RF carrier signal. These effects are important for the proper functioning of the cable as a part and also for measurements for those parts, devices or circuits which require ac for their operation. As a matter of fact, the measurement of the amplitude and phase shift during the radiation pulse can be applied within certain limits to resistors, capacitors, and inductors, as well as to the cables. Compared to dc measurements where the noise signals from the cable are often undistinguishable from the true changes in part characteristics, the RF measurements offer the possibility to suppress the noise contribution by simple filtering techniques.

The various aspects of cable response to nuclear radiation discussed above were studied in three major experiments and one small follow-up conducted at the Sandia Pulse Reactor Facility (SPRF), Albuquerque, N.M., during 1961 and 1962, by personnel of USAELRDL. These experiments are identified in this report as follows:

August 1961 – SPRF I, reported in Reference 1
April 1962 – SPRF II, reported in References 2 and 3
September 1962 – SPRF III)
December 1962 – SPRF IIIA) reported here.

OBJECTIVES

One objective of SPRF III was the independent measurement of noise signals generated in the center conductor and in the shield of RG59 B/U and RG62 A/U cables as a function of dc voltages applied to either conductor in various modes and as a function of the radiation exposure history of the samples.

Another objective was the measurement of changes in the transmission characteristics of the cables by the observation of transmitted RF signals as well as by direct phase and amplitude measurements. The separation of the RF carrier from the superposed noise signal was attempted by a high-pass filter.

EXPERIMENTAL PLAN

In planning the experiments, the above objectives were translated into seven exposure schemata called "frames" each of which consisted of a six-shot program for one day. In this program, the conditions were usually held unchanged in the first three shots and they were varied systematically thereafter.

In the interest of a logical and more readily understandable presentation we will discuss our results in a sequence different from that of the frames, but a brief description and a glance at Tables 1 through 10 will show the particular objective of each frame and their mutual relationship.

Frame 1: Re-exposure of nine cables from SPRF II offers a comparison of the previously used hairpin configuration with the straight cables used in SPRF III and also some information on recovery during a five-month rest period. (Included also one sample from Frame 5.)

Frame 2: Tests of center conductors without the shield and jacket which were expected to yield their intrinsic response.

Frame 3: Sequence of exposures with both conductors at the same potential.

Frame 4: Sequence of exposures in which the voltage was applied to either the center conductor or the shield alone.

Frame 5: Intended to determine the effect of steady-state pre-irradiation under simultaneously applied high voltage.

Frame 6: Phase and amplitude measurements of RF signals.

Frame 7: a. 100-kohm resistor connected to the center conductors of two coaxial cables (RG59 B/U) whose shields are kept at the same potential as the center conductors.

b. 100-kohm resistor connected between center conductor and outer shield of a tri-coaxial cable (21-527) with inner shield kept at center conductor potential or floating ground. Open cable for comparison.

c. Multi-Conductor Mylar Ribbon Cable.

d. Modulation of RF carrier signals and their separation from ordinary noise signals by filtering.

SPRF IIIA: Repeat exposure of complete Frame 5 plus one sample exposed in Frame 1 of SPRF III.

EXPERIMENTAL PROCEDURES

The experiments of the SPRF III series were conducted essentially using the instrumentation and procedures developed for the preceding series. The only major change consisted in adpoting a nearly straight cable configuration instead of the previously used hairpin loop. In order to keep the cables reasonably straight and to arrange them so that they pointed radially to the reactor head, they were laid in grooved wooden trays. The cable ends were potted in epoxy to avoid air ionization effects.

The measuring resistors for the noise signals were 1,000 ohm for the center conductor and either 1,000 ohm or 100 ohm for the shield. Almost all noise measurements were made on both conductors simultaneously.

Other experimental conditions pertaining to individual frames or experiments will be described in the appropriate sections of the report.

The bulk of our measurements were made on two coaxial cable types, namely:

1. Coaxial Radio Frequency Cable RG59 B/U, according to MIL-C-17/29A.
2. Coaxial Radio Frequency Cable RG62 A/U, according to MIL-C-17/30.

A small number of measurements were made on these cable types:

3. Tri-Coaxial Radio Frequency Cable 21-527, Commercial.
4. Electrical Telephone Cable (Infantry Wire, Twisted Pair) WD-1/TT, according to MIL-C-13294.
5. Television Antenna Cable, 300 ohm, Commercial.
6. Multi-Conductor Mylar Ribbon Cable, Commercial.

EXPERIMENTAL RESULTS

1. TRANSIENT NOISE SIGNALS

The Transient Noise Signal of the RG59 B/U Cable

This topic was the central theme of the SPRF III and SPRF IIIA experiments and consequently measurements of this nature were included in every frame except 6. It would be confusing to discuss the results frame by frame, however, because in several instances the true response behavior is masked by unexpected extraneous effects which can be identified and explained only in the light of the complete results from all experiments performed. Our discussion will therefore always begin with an example which we consider typical for the particular condition under consideration and proceed from there to the observed anomalies and their causes.

a. The Noise Signal in the Center Conductor

We begin with the elementary case in which no external voltage is applied to either conductor of the cable. What we believe to be the typical response signal is found in Sample 59-12 as measured in Shots 1, 2 and 3 of the SPRF IIIA series listed in Table 7 and likewise in Samples 59-4, 59-5 and 59-6 as exposed in Shot 16 of Frame 3, Table 4, and Samples 59-17 and 59-18 as shown in Shot 28 of Frame 7, Table 8.

The results can be summarized by stating that the response current signal never exceeds the range from $-10\mu a$ to $+10\mu a$. Although it is likely that this range is actually even smaller, we cannot make a more definite statement because the sensitivity threshold of our measuring system was too close to the level of the observed signals.

The behavior with no applied voltage is characteristically altered if the sample has a history of one or more exposures in which a voltage has been applied. Examples of such sequences are found in Shots 1, 2 and 3 of the SPRF IIIA series, Samples 59-11, 59-13, and 59-20, Table 7 and in Shots 7, 8, 9 and 10 of Frame 4, Samples 59-7, 59-8, 59-9 and 59-10, Table 6.

For the no-voltage Shots 3 and 10 in SPRF IIIA and Frame 4, respectively, the response current of the above samples ranges from $-20\mu a$ to $+65\mu a$, or at least twice and perhaps as much as ten times the signal magnitude of the normal no-voltage case.

Closer inspection of the data shows that the polarity of the potential applied between center conductor and shield determines uniquely the flow direction of the current in the ensuing no-voltage shot. A negative current flow occurs whenever either a positive voltage was applied to the center, or a negative voltage to the shield, in the preceding shot; a positive current results if the opposite potentials prevailed.

This behavior is strongly reminiscent of bi-stable memories. In computer terminology the no-voltage signal would be a readout whose polarity is determined by the previously stored information. It is believed that under the combined influence of the applied potential and the nuclear radiation, space charges are deposited or "trapped" in the cable dielectric, and they are released by a subsequent radiation pulse only if the applied potential is markedly different from that of the "write" shot. This picture requires that the readout should be essentially destructive, because the space charge which carried the information is released or redistributed in the process. Evidence for this fact will be presented later.

Obviously the memory effect should occur only if a potential difference exists between the two cable conductors during the write shots, but not if both are at the same potential, regardless of whether it is equal to or different from the ground potential. This conclusion is borne out by the results of the no-voltage shots 16 and 28 in Frames 3 and 7, Tables 4 and 8, so that we were able to cite them as examples for the $-10\mu a$ to $+10\mu a$ range typifying the cable in the initial no-voltage exposure, because in the earlier exposures both conductors had always been at the same potential and consequently no space charge was formed.

In the SPRF IIIA series, Table 7, Samples 59-11, 59-13 and 59-20 are exposed in Shots 1 and 2 with a voltage of 268V applied to the center conductor. As compared to the results of the no-voltage Sample 59-12, the current signals are increased five or perhaps as much as ten times and their polarity is in keeping with that of the applied voltage. In the second exposure, the signal is reduced in magnitude by more than one half; this fact is consistent with the assumed space charge build-up which remains at least partially from one shot to the next and thus requires decreasing charging currents. The total charge is, of course, released in Shot 3 as described before.

In the concluding Shots 4 and 5 of SPRF IIIA, Table 7, and in Shots 11 and 12 of Frame 4, Table 6, the samples go through two additional voltage steps, namely reapplication of the original voltage and reversal of its polarity.

In terms of the memory effect, we would expect the current signal to repeat its initial magnitude upon reapplication of the voltage and to yield a readout of twice this magnitude and with the opposite sign upon the reversal of the applied voltage.

Qualitatively, the observed results are consistent with this expectation, but the doubling of the signal is not observed in all cases. This could well be due to the loss of the stored information by the leakage of space charges during the time between the shots.

From the results considered so far, we can summarize the response of the RG59 B/U center conductor:

(1) Without applied voltage, the signal currents during the radiation pulse are mostly below $10\mu a$ in absolute magnitude.

(2) If a voltage of $\pm 268V$ is applied to the center conductor, the signal increases by one order of magnitude or less and its polarity is that of the applied voltage.

(3) If the level or polarity of the applied voltage is changed in successive shots, the response will depend upon the nature of this change. If a positive or negative voltage is removed, the signal will be negative or positive, respectively. If the voltage is reversed from positive to negative polarity, the signal will be negative and vice versa. The magnitude of the signal upon voltage removal is usually equal (but opposite in sign) to that observed in the first shot; upon reversal, the current magnitude tends to double.

It should be noted that the data which we have cited in support of this summary description constitute only a minority of the center conductor measurements contained in this report. The deviations of the nonconforming majority of cases are mostly related to the behavior of the shield current signals, and therefore we postpone their discussion until we have described the shield response.

b. The Noise Signal in the Shield

At first we shall consider again the case where no voltage is applied to the conductor, in this case the shield. The data are included in Frame 4, Sample 59-7, Shots 7 through 11,* Table 6, and in the SPRF IIIA series, Shots 1 through 5, Table 7.

The shield current values of all samples lie in a range between $-50\mu a$ and $-175\mu a$. Typically, they exceed the absolute values of the center conductor current by about one order of magnitude and remain unchanged in repetitive shots. The magnitude of the shield current appears to be influenced by the changes of current polarity in the center conductor in conjunction with its memory behavior described above. Whenever the center conductor yields one of the positive or negative readout signals, the shield current increases or decreases by a comparable amount as though the readout currents were flowing directly between the center conductor and the shield and thus being added to the "normal" negative shield current.

Summarizing the evidence for the shield currents without applied shield voltage, we conclude that they should be generally expected to lie between $-50\mu a$ and $-200\mu a$ if the voltage applied to the conductor or its changes from one shot to the next do not exceed the range from +268V to −268V. A positive readout signal occurring in the center conductor tends to increase the negative shield currently while a negative readout decreases it.

Experiments in which the shield carried a positive or negative voltage of 268V are reported in Frames 3, 4 and 7. In Frame 3, Samples 59-4 and 59-6, Table 4, the center conductor and the shield always carried the same voltage which was supplied by independent batteries. Similarly, a voltage is applied to both conductors of Samples 59-17 and 59-18 in Frame 7, Table 8. The center conductors of these two samples were connected by a 100,000-ohm resistor, thus forming a continuous current path. With +268V applied to one and −268V applied to the other center conductor, a quiescent current of 5.4 milliamperes was allowed to flow continuously in this circuit. Except for Shot 26, the shield voltages of both connectors were kept equal to their respective center conductor voltages, but the shields were isolated from each other. In Shot 26, the shield voltage was reduced to +134V and −134V on Sample 59-17 and 59-18, respectively, thus reducing the potential between shields from 536V to 268V. In Frame 4, Table 6, Samples 59-9 and 59-10 are studied with the voltage applied to the shield only and the center conductor carries no impressed voltage.

If there are any differences in the shield currents caused by the different modes in which the voltage was applied,they are completely overshadowed by the fact that the applied voltage increases the shield current by a factor of about 30 or 40. The flow direction of the shield current is dictated by the polarity of the applied voltage.

In Sample 59-4 of Frame 3, Table 5, the absolute current values range from 3,000 to

*We disregard the zero value in Shot 12 because we strongly suspect a connection failure in this case.

3,500μa; since no potential exists between the center conductor and the shield, no training effect, i.e., decreasing signal magnitude in repetitive shots is expected and none is observed. Upon removal of the applied voltage in Shot 16, the current drops to a level of <−500μa which, because of low reading sensitivity in this particular measurement, is believed to be consistent with the previously postulated limit of −200μa for the no-voltage condition.

In Sample 59-6 of Frame 3, the current is somewhat higher and ranges from 4,000 to 4,750μa, in absolute magnitude. Again, there is no indication of training, as expected. Upon removal of the applied voltage in Shot 16, the current drops to the same <−500μa level as the previous sample.

The two Samples 59-17 and 59-18 in Frame 7, Table 8, agree very well with the behavior of the samples just described, particularly in Shot 26 where the potential between their shields is reduced to 268V. The values in Shot 27 are perhaps somewhat anomalous because they do not return to the initial current levels of Shot 25. This seems to suggest a training effect which, however, in this case would be unexpected. There is no ready explanation for this behavior. In Shots 28, 29 and 30, the response is in keeping with that of the previous samples; the no-voltage values are within the postulated range on reapplication and reversal of the voltage, the current levels reach their highest values and reverse symmetrically from Shot 29 to Shot 30.

In the initial shots of Frame 4, Table 6, the shield current of Samples 59-9 and 59-10 follows closely the pattern just described. In Sample 59-9 with an applied voltage of +268V on the shield, the current ranges from +5,400 to +6,000μa, and in Sample 59-10 with an applied voltage of −268V, it ranges from −4,000 to −4,200μa with one reading missing because the signal went off-scale. Without applied voltage in Shot 10, the current in Sample 59-9 drops to the familiar <−500μa value, but in Sample 59-10, it becomes slightly positive. This is not in keeping with the negative current range from −50 to −200μa considered normal for this case, but the sensitivity was very low and the deviation from the normal behavior so small that it could have been caused by any slight disturbance in the measurement.

A more pronounced anomaly, however, occurs in Shot 12 where both Samples 59-9 and 59-10 fail to yield the symmetrical current reversal expected with the reversal of the applied voltage. A comparison of the results in Shot 12 with those in Shot 10 shows a strong similarity of the corresponding signals in the conductors of both samples. This suggests that the condition of Shot 12 was a repeat of that of Shot 10, i.e., no applied voltage, rather than the scheduled reversal of the voltage applied in Shot 11. Although it is no longer possible to ascertain this fact beyond any doubt, the possibility of an error in applied voltage cannot be denied. In view of this uncertainty, it is believed best to disregard the data of Shot 12 until they can be verified in future experiments.

The behavior of the current peak values in the RG59 B/U cable shield can be summarized:

(1) Without applied voltage on either conductor, the shield current is typically about −100μa. There is no change of this current level due to training through at least three exposures.

(2) Application of a voltage of ±268V to the center conductor only does not by itself change the current level in the shield, but an increase or decrease current is observed if the level or polarity of the center conductor voltage is changed significantly from one shot to the next. This change in shield current level appears to be essentially a superposition of the memory readout current of the center conductor and the intrinsic shield response.

(3) With a voltage of ±268V applied to the shield, the current increases in absolute

value by more than one order of magnitude (typically 30 or 40 times) and its flow direction is dictated by the polarity of the applied voltage. There is no significant change of the current level due to training through at least three repetitive exposures.

(4) The response of the shield with applied voltage does not appear to be affected significantly by the presence or absence of a potential between shield and center conductor; at least this is true in the cases studied here, with the center conductor either without applied voltage or carrying the same voltage as the shield.

c. The Effect of the Shield Current Upon the Signal in the Center Conductor

We have, so far, avoided reference to a number of results which do not seem to fit our description. These are measurements of RG59 B/U center conductors whose response was not a single pulse but an oscillation. Such results occur in many instances in Frames 2, 3, 4 and 7 and they were also observed in SPRF II and earlier experiments by us and other experimenters. Ikrath[4] has theoretically treated the possibility of oscillatory signals using a lumped circuit model.

With the discovery of the great disparity between the current flowing in the shield and that flowing in the center, which was first described by E. Both, H. P. Bruemmer, and W. Schlosser as a result of SPRF II, a more direct interaction mode suggested itself, namely the capacitive coupling between the two conductors. Further analysis* revealed that the open cable with its grounded measuring resistors on both conductors as used in SPRF experiments constitutes a differentiating network for the voltage generated by the shield current pulse across its readout resistor.

Under conditions simulating the observed excitation in one of the actual samples of the SPRF experiments by electrical input signals duplicating the current magnitude and the "equivalent" frequency of the radiation pulse, the peak value of the differentiated signal was found to lie at about .5% or at about 5% of the impressed shield current depending on whether the shield measuring resistor was 100 ohm or 1,000 ohm. Considering the typical center conductor response current magnitude of about $10\mu a$ as described in Section 1a, we may expect the differentiated oscillatory center conductor signal to become equal or predominant at a shield current level of about $2{,}000\mu a$ or $200\mu a$ in these two cases.

The experimental results are in excellent agreement with the expected behavior. In Frame 3, Table 4, where the measuring resistance in the shield leg was 1,000 ohm, the peak-to-peak values of the center conductor current average out to 4.9% of the peak current in the shield, and for Frames 4 and 7. Tables 6 and 8, where the measuring resistor was 100 ohm, the corresponding average is .75%. The somewhat poorer agreement in this case is caused by the greatly reduced signal level in the center conductor and the concurrent loss in accuracy of the readings.

We can therefore state that the oscillatory signal in the center conductor is caused by the differentiation of the shield current signal. Obviously, however, the "intrinsic" center conductor signal must be superposed on this oscillation. We find indeed that where the oscillatory signal is small on account of the lower resistance value in the differentiating circuit, it is also highly unsymmetrical in most cases, while with the higher signal level in the 1,000-ohm circuit, the differentiated current becomes dominant and, therefore, almost perfectly symmetrical.

The consequences of the above findings for the performance of measurements at nuclear pulse reactors are fairly obvious. They will be discussed in a later section.

*See Appendix A.

d. The Effect of Parasitic Interaction Between Neighboring Cables

The shield currents of Sample 59-5 in Frame 3, Table 4, and of Sample 59-8 in Frame 4, Table 6, are greatly different from our "typical" values. Except in the no-voltage Shots 16 and 10, respectively, their magnitude is too high and, in the case of Sample 59-5, even their polarity is wrong. In both cases the only plausible explanation for the anomalous behavior is a parasitic interaction between neighboring cables.

In the case of Sample 59-5, the source of the parasitic current is possibly the shield of Sample 59-6. Some 15 to 17 percent of the current flowing through this sample are "drained off" and return to the ground via the shield of Sample 59-5. Without applied voltage in Shot 16, the current in both shields returns to the normal behavior.

The fact that the shield current in Sample 59-5 is real can be satisfactorily proven by its differentiated signal appearing in the center conductor. The signal is well pronounced in spite of the relatively low shield current, because the shield resistor in this case is 1,000 ohm.

The presumed "donor" of the parasitic current flowing through the shield of Sample 59-8 in Frame 4, Table 6, could be Sample 59-9 which returns about 17 to 20 percent of its current via Sample 59-8. Here, too, the no-voltage Shot 10 verifies the normal behavior of the shields. The absence of the differentiated signal in the center conductor is caused by its relative smallness. With the 100-ohm resistor used in this cable shield and the current of about 1,000μa, it would be expected to be no more than about $\begin{matrix}+3)\\-3)\end{matrix}$ which would only appear as a distortion of the already very small deflection.

The observation of parasitic currents was an unexpected by-product of our experiments with applied voltages on the cable shields. Their magnitude was at first quite surprising considering the fact that the cables were spaced about 3/8 inches apart in the slots of a wooden tray. We believe now that a metal strip across the tray used to hold the cables down in their slots may have greatly intensified the interaction which otherwise might have been unnoticeable.

At least one other instance of definite parasitic interaction was observed in the multi-conductor ribbon cable. It will be discussed in the appropriate section.

e. The Noise Signal in the Shieldless Center Conductor

In order to determine the intrinsic response signal of the center conductor without the suspected contribution from the shield, several samples were tested without the outer jacket and the braided shield. The exposed end of these samples was cast in epoxy in the same way as all the other samples to avoid direct contact between the conductor and the ionized air.

The results of this experiment are listed in Frame 2, Table 3 for Samples 59-1, 59-2 and 59-3. In mose instances, the response signal is oscillatory. The similarity of the behavior to some of the results in Frames 3 and 4 is striking, and it suggests strongly that the cause is the same in both cases. It is therefore assumed that the ionized air surrounding the insulated center conductor forms a pseudo-shield which conducts free charges to the nearest ground. This assumption is supported by the fact that the oscillatory signal persists in Shot 16 where the voltage sources of all samples under test at the time were disconnected. Closer inspection of the data reveals that the oscillatory signal in all shots except 16 contains a strong negative component even where the applied voltage is positive. This negative "bias" is particularly striking in Sample 59-2 which carried no voltage at any time, but which shows drastic "sympathetic" changes when the voltage on other samples is changed. The source for this negative "across-the-board" bias may be an interaction of the parasitic variety with other cables near the reactor.

The negative bias would also explain the fact that the only values in this experiment which are not oscillatory occur where the applied voltage is negative or where no voltage is applied. Only in these cases can the combination of the regular negative response signal and the negative bias pulse become strong enough to push the superposed oscillatory signal below the zero line, thus changing its influence to a mere distortion of the observed pulse.

The actual current values observed in the five cases of true pulse signals range from $-20\mu a$ to $-60\mu a$; therefore, they fall within our established limits despite the unknown contribution from the parasitic bias.

The interpretation of the measurements which yielded strong oscillatory signals is impossible since the polarity, magnitude, and pulse shape of the ionization current in the pseudo-shield and the impedance of its path to ground are unknown and may vary widely from sample to sample and from shot to shot.

The results of this experiment were contrary to our original expectation that a shieldless center conductor should yield a cleaner response. Even if one would avoid the parasitic contribution which apparently crept into some of our results, the unpredictable ionized air current signal would not permit definite quantitative measurements. As we have seen, the data become much more consistent when the regular shield is used in the proper manner.

f. The Effect of Steady-State Radiation under Applied Voltage Upon the Response of the RG59 B/U Cable

The training effects observed in repeated shots suggested the attempt to age the cables by steady-state irradiation under applied voltage. This treatment was believed, at least hypothetically, to establish a space charge in the cable dielectric which would tend to reduce the cable signals by the repulsion of charges of equal polarity.

In order to test this assumption, Samples 59-11, 59-12, 59-13 and 59-20 were exposed for 7 hours to a steady-state power run of the Sandia Pulse Reactor at a power level of 500 watts. During the entire period of exposure, a voltage of +1.8KV was applied to the center conductors with the shield at ground potential. The total gamma dose at the location of the cables was about 10^3 Rads.

The samples were exposed in the form of flat coils arranged about 6 inches away from the reactor screen. For the measurement, they were strung out in the grooved wooden trays and connected to the mobile laboratory outside. The time interval between the steady-state irradiation and the first SPRF Shot was 10 hours. All six shots on Samples 59-11, 59-12 and 59-13 were completed within 24 hours after the beginning of the aging treatment. Sample 59-20 was exposed one day later.

The results obtained in these samples are listed in Frame 5, Table 7. The common feature which is most readily apparent is the very small magnitude of the shield current. In most cases the sensitivity of measurement was too poor to make any statement more quantitative than saying that the current was smaller, and perhaps much smaller than $50\mu a$. In only one case, Sample 59-11 in Shot 8, does the current exceed $50\mu a$.

We have little doubt that the marked depression of the shield current is caused by the aging treatment, although it is hard to find a plausible explanation for this response. It is also strange that it persists virtually undamaged through all six shots of the SPRF III series in spite of several write and read signals induced in the center conductor. We have never observed a similar effect in cables subjected to a series of training pulses with applied voltage at SPRF.

The behavior of the center conductor current is likewise affected by the treatment. In Samples 59-11 and 59-12, the initial strong negative values may seem anomalous at first sight, as compared to the SPRF IIIA results, but they are in keeping with the fact that in the treatment the positive voltage was applied to the center conductor and that therefore the first SPRF Shot 7 is a readout shot in both cases, if we consider the applied voltage of +268V in Sample 59-11 as small compared to the 1.8KV in the treatment. In the subsequent shots both samples behave as expected. We obtain another readout in Shot 10 from Sample 59-11 and the proper write and reversal readout signals from both samples in Shots 11 and 12.

Sample 59-12 begins with an unusually small signal which reaches the normal $-5\mu a$ in the third shot and thereafter behaves normally through the read-write-reversal sequence.

The last Sample 59-20 in Frame 5, Table 7, was exposed separately on the second day after the aging treatment together with samples of Frame 1, Tables 1 and 2. Its behavior is more erratic than that of the samples in Frame 5. In four shots the shield current shows oscillations having peak-to-peak values in excess of all the shield currents in Frame 5, and in two shots the oscillations are observed in the center conductor, where their magnitude in the final Shot 24 is entirely beyond the normal range. We ascribe the anomalous behavior tentatively to the fact that this sample was exposed, together with the long hairpin loop samples re-tested from SPRF II in Frame 1, Tables 1 and 2. Some of the RG62 A/U samples in this frame developed very large shield currents although the shields were not biased, and it is not impossible that Sample 59-20 was affected by parasitic interaction. In spite of the anomalies in the shield current in four out of the six shots, the center conductor response of the cable is normal in all shots but Shot 24.

The samples of Frame 5 of the SPRF III series were re-exposed in an additional five-shot series named SPRF IIIA, Table 7, after a rest period of about ten weeks. We have discussed the values obtained in this series at the very beginning because they are in our opinion the most representative values of RG59 B/U cable we have obtained so far. We see that all the shield values are now up to the $-100\mu a$ level while the magnitude of the center conductor values has undergone relatively little change. As was noted earlier all results are highly consistent, including those of Sample 59-20 which had behaved so erratically in Frame 5 of SPRF III.

Concerning the persistence of the effects of the aging treatment through the ten-week period between SPRF III and SPRF IIIA, we conclude from the data that the shield current response has definitely returned to normal from the previous state of "suppression." The only apparent effect of the aging treatment upon the center conductor had been the negative readout in the initial shots of Samples 59-11 and 59-12. By changing the condition of applied voltage in several shots of SPRF III, we have apparently wiped out whatever effect the treatment may have had and therefore we do not find any statistically significant change of the behavior in the SPRF IIIA series.

g. Results of Re-exposure of RG59 B/U Cables Originally Studied in SPRF II

This experiment is summarized as part of Frame 1 in Table 1. It contains five samples of RG59 B/U cables which had been measured earlier in the April 1962 series of SPRF II and which were re-exposed in a six-shot series under varying voltage conditions in the September 1962 series of SPRF III.

This experiment had several objectives. First, it was expected to provide a connecting link between the results of the two experimental series. This was necessary because the length and configuration of the samples had been drastically changed from the 35-ft hairpin loop to a 16-ft straight run. Secondly, we wanted to extend the measurements of the signals in the individual cable conductors which in the SPRF II series had been limited to a very small number of tests and which had not included any cases with applied voltage. Thirdly, we wanted to see whether the "training" effects, i.e., the reduction of signal amplitude in successive shots observed in SPRF II had persisted or recovered during the five months of "rest" between the two series. This question is of practical importance and of theoretical interest as well.

It turned out that the results of all five cables in the SPRF III series were much more consistent than they had been in SPRF II. Undoubtedly, this is due primarily to the more careful layout of the cable samples in the grooved wooden trays used in SPRF III as compared to the rather haphazard arrangement of a major part of the cable length in SPRF II. In Table 1, the SPRF II results are shown in the ten columns to the left and the SPRF III results in the six columns to the right.

The plan was to re-expose each sample in the first shot of the SPRF III series under the same condition in which it had last been tested in SPRF II, and to change the applied voltage only after one or several re-exposures. We also used the same measuring method as in the previous experiment, i.e., either the center off-ground and the shield grounded or both center and shield off-ground in the first two re-exposure shots; all subsequent measurements were made on the individual conductors.

In general the results of all samples in the SPRF III re-exposure are in excellent qualitative agreement with the typical behavior which we have found in our new experiments and described in the preceding sections. The magnitude of the observed signals is much greater, particularly for the center conductor currents, than would be expected on the basis of the greater total sample length. Whether this "bonus" signal is due to the greater sample length in the immediate vicinity of the source has not yet been determined.

Sample 59-13-138 had been exposed ten times in SPRF II. In the tenth shot, it was measured with the individual conductor method. The result of the first three exposures in SPRF III, Shots 19, 20 and 21, agree very well with those in the final shots of SPRF II, an apparent confirmation of the persistence of the "training" effect. The strong signal upon application of +268V in Shot 22 tends to support this conclusion. It also causes the expected increase in the shield current, and in the final Shots 23 and 24 we observe readout and a negative write signal which are also accompanied by the appropriate change in the shield current.

Sample 59-16-146 does not show the close agreement between SPRF II and SPRF III results, possibly because the sample had been exposed only twice in SPRF II. In all SPRF III Shots, it resembles very closely Sample 59-16-138 when taking into account the opposite direction of the sequence of applied voltages.

The positive polarity of the shield current of Sample 59-16-146 in the initial measurements of SPRF II constitutes by now the sole exception to the negative shield current polarity encountered in all other no-voltage shots, except those affected by a readout signal from a previous shot with applied voltage. Since the better condition can be ruled out for the initial SPRF II measurements of Sample 59-16-146 and since a thorough check of all the experimental records confirmed the positive signals beyond a reasonable doubt, we must accept them as presently unexplainable anomalies.

In SPRF III, the sample conforms with the normal shield behavior pattern; it shows the expected change with the readout signals in the center conductor. The oscillatory behavior of the shield current in Shot 22 will be considered, together with that of other samples, later on.

Sample 59-7-125 was chosen for re-exposure because it had shown an unusual change from a negative to a much larger positive signal in the first two shots in SPRF II with +268V on the center conductor. The re-exposure results in SPRF III line up nicely with the second value in SPRF II, and they may be taken to indicate that whatever training may have been imparted on the sample in SPRF II persisted through the five-month interval.

The value of $-50\mu a$ for Sample 59-7-125 in the first shot and all similar values of Samples 59-5-115 and 59-13-137 in SPRF II are clearly inconsistent with the newly established behavior of the RG59 B/U center conductor carrying +268V and with the results on the very same samples in SPRF III. An attempt to explain the discrepancies cannot be much more than a surmise, but there is no doubt that the values would fit nicely if somehow the scheduled voltage had not been applied in SPRF II, perhaps because the battery may have been inadvertently by-passed. This assumption is also consistent with the write signals observed in the first Shot of SPRF III for Samples 59-5-115 and 59-13-137.

At any rate, the results of all Samples in SPRF III are very well behaved and confirm every statement made in our description above except for the difference in magnitude of the signals caused by the cable length and configuration. The greater length with its attendant higher capacitance is probably also responsible for the appearance of oscillations in the center conductor when the shield currents are close to or even below $-200\mu a$. The training in repetitive shots and the memory readout upon changing the applied voltage are consistently observed.

One anomaly practically without counterpart in the experiments on straight cables in the SPRF III series is the appearance of oscillations in the shield current. The differentiation of the current in one conductor and the injection of the differentiated signal into the other which we showed earlier to be the cause of oscillations in the center conductor is, of course, also operative in the other direction, since our circuit is entirely symmetrical. As much as we know, however, the contribution to the oscillations in the shield from this source would account for only a minor part of their observed peak-to-peak values.

The oscillations occur only when a rather strong negative readout signal from the center conductor reduced the magnitude of the normally negative shield current. While in some such instances the resulting shield current becomes a regular positive pulse, they are outnumbered by those where it becomes an oscillation with a predominant initial negative peak followed by the smaller positive peak. The "phase" of this oscillation is in agreement with the differentiation mechanism and possibly the negative bias is due to some extent to its contribution. The major part of the oscillatory signal cannot be explained at present.

The voltage schedule used in Frame 1 differs from that of the experiments described previously by the fact that the reversal of the voltage is accomplished in two steps rather than in one. Each step yields a signal of equal magnitude and opposite polarity as compared to the preceding write signal obtained when the voltage is first applied. This supports our earlier contention that the signal upon reversal should have twice the magnitude of the single write or read signal.

With respect to the original objective the re-exposure experiment has been useful in more ways than had been expected. The results of the cables in the SPRF III series are much more consistent than those of the SPRF II exposures, so much so that we now have reasons to question some of the earlier data or the conditions under which they were obtained.

Compared to the signal levels now found in the re-exposed cables in hairpin loop configuration, the new straight sample arrangement showed a much greater improvement than could be expected from the reduction in length. The shield current of the straight cable is about one third and, surprisingly, the center current is only about one tenth of the corresponding signals in the hairpin loop. This fact is obviously of great practical significance for measurements at the pulse reactor facility.

The individual leg measurements on the re-exposed samples proved very useful not only in determining and understanding this behavior but particularly in the comparison of the response of the hairpin configuration with the straight sample.

The question of the recovery from the training effects of SPRF II was not conclusively answered, mostly because some of the reference data from the earlier experiment have now become questionable. The evidence from the "good" data appears to support the view that the training effects achieved by repeated exposure are still operative after a five-month rest period, provided that the re-exposure is performed under the same condition of applied voltage as the last shot of the preceding series.

The Response of the Tri-Coaxial Cable Type 21-527

This cable is a commercially available modification of the RG59 B/U cable from which it differs by the addition of a second shield and an outer jacket. Two samples of this cable designated Sample 21-527-1 and 21-527-2 were included in Frame 7, Table 9.

The purpose of this experiment was (a) to determine whether the additional shield has an appreciable effect upon the cable response, and (b) to compare the performance of this cable with that of the two RG59 B/U Samples 59-17 and 59-18 when used for a current measurement with a guard potential. The latter measurements will be discussed in a later section.

The samples were always exposed with the outer shield grounded through a 100-ohm measuring resistor; the exposed end of Sample 21-527-1 was electrically open, whereas in Sample 21-527-2 a 100-kohm carbon film resistor was connected between the center conductor and the outer shield (see Appendix B). The cable ends were potted in epoxy in the usual manner.

The center conductor of both samples carried an applied voltage of +268V in the first three shots, 25, 26 and 27, and went through the sequence of 0 volt, +268V, and −268V in the subsequent shots 28, 29 and 30. The inner shield acted as a guard in most cases, i.e., its applied voltage was kept identical with that of the center conductor in polarity and magnitude, but the exposed end was always electrically open. In Shot 27, however, the inner shield was disconnected from the battery and from the ground and left at a floating potential. While in all other cases the full potential existed between the inner and the outer shield, it was more evenly distributed over the space between the center and the outer conductor in Shot 27.

The response of the center conductor is practically identical in both samples throughout the five shots for which readings were obtained. The signal magnitude is somewhat smaller than expected from an RG59 B/U center conductor with applied voltage. More puzzling, however, is the fact that in Shots 26 and 29 the signal polarity opposes that of the applied voltage, a behavior which is inconsistent with our findings on the RG59 B/U cable.

In Shot 27 where the inner shield was floating we find an oscillatory signal with a predominant positive component, and the response in the no-voltage Shot 28 is in keeping with the expected readout. In the final Shot 30 the signals become very small.

The response of the inner shields is also practically identical for both samples and the signal polarity agrees with that of the applied voltage. Compared to the behavior of the shield of the regular RG59 B/U cable, we note a tremendous difference in signal magnitude in the tri-coaxial cable: while the typical signal level in the RG59 B/U was about 3,000μa or 4,000μa, it now ranges only from 50μa to 100μa.

There can be little doubt that the credit for this drastic reduction of the signal level belongs to the outer shield, although the mechanism by which it achieves this result is presently not known in any detail.

The behavior of the inner shield in the no-voltage Shot 28 is unusual because its signal is positive and much smaller than that of RG59 B/U under the same test condition. At present we can do no more than point out this difference, but one could speculate if this might not be the real intrinsic shield behavior, while the values in the $-100\mu a$ range which we defined above as normal might still be due to the ionized air surrounding the cable rather than to a direct radiation effect.

The outer shields of both samples do not show the close agreement in their signal currents observed in the other conductors, except in the no-voltage Shot 28 where their $-50\mu a$ value is in excellent agreement with the typical behavior of the regular RG59 B/U cable shield. In the remaining shots, both samples, particularly Sample 21-527-1, show signs of a parasitic interaction, which leads to abnormally high signal levels and even cases of wrong polarity.

The source of the parasitic current is very likely the pair of Samples 59-17 and 59-18 which were observed in Frame 7 with the results listed in Table 8. These cables were taped together as a unit and their exposed ends with the 100-kohm resistor were all potted together in epoxy. While this arrangement had probably little or no effect on the behavior of this pair with respect to its overall response, it does affect its characteristics as a source for parasitic currents. Most of the current signal in the shields constitutes a continuous flow, entering one shield and leaving the other, thus having little effect on the outside. This is no longer true when the current in one shield differs significantly from the other. This occurs in Shots 25, 26, 27, 29 and 30 with current unbalances of $-450\mu a$, $-940\mu a$, $+200\mu a$, $+800\mu a$ and $-1{,}000\mu a$, respectively.

An object at a distance would therefore only "see" the influence of these excess currents. We would like to note here that the measurement of the large currents is not always very accurate and that therefore the above differences should be considered only as approximate values.

Sample 21-527-1 shows a much higher level of parasitic pickup current than Sample 21-527-2 and is therefore believed to have been closer to the source. Its current signals follow essentially the pattern of the "source" signal variations although the correspondence is not quantitative probably because of the limited accuracy of the source current values.

Sample 21-257-2 was much less affected, and its values in Shots 26 and 27 are indistinguishable from the normal response of the regular RG59 B/U cable. The fact that an interaction occurred, however, is clearly apparent from the increased signal in Shot 29 and even more from the reversal of the polarity in Shot 30.

The Transient Noise Signal of the RG62 A/U Cable

Noise measurements on RG62 A/U cables were included in Frames 1, 2, 3 and 4 of the SPRF III series in direct comparison with the samples of RG59 B/U which were exposed in the same shots and with the same applied voltage schedules. This juxtaposition was hoped to clarify the distinct differences in the behavior of the two cable types established in the SPRF I and SPRF II series, namely a much greater magnitude of the RG62 A/U signal in the initial exposure and its drastic reduction in repetitive shots.

a. The Noise Signal in the Center Conductor

Without applied voltage, the center conductor of Sample 62-5 yields a signal of $+750\mu a$ in the initial Shot 13 of Frame 3, Table 5. In the repeat Shot 14, it decreases by about one order of absolute magnitude and it reverses its polarity. In all subsequent Shots, 15 through 18, the signal is smaller than $10\mu a$ and drops below the sensitivity threshold of $\pm 5\mu a$ in Shot 18.

The companion Samples 62-4 and 62-6 carry applied voltages on both conductors, but in such a way that the center conductor and shield of each are always at the same potential. It is interesting to note that except for the obvious oscillatory contribution from the shield current differentiation, the center conductor response of both samples is practically indistinguishable from that of Sample 62-5. The similarity is particularly striking in Shot 13 where, despite the differences of applied voltage and the drastic differences in shield current caused thereby, the center conductor signals of all three samples are strongly positive and comparable in magnitude.*

The behavior of all samples in the remaining shots agrees very well with our earlier results with respect to the drastic reduction in signal magnitude. In addition, we find now that this reduced level persists throughout the shots in which the voltage is removed, reapplied and reversed, thus confirming our conclusion that memory read and write signals occur only if a potential difference exists between the conductors.

Another interesting result is observed in the no-voltage Shot 16. The center conductor signals of all samples in Frame 3, Tables 4 and 5, i.e., of both cable types RG59 B/U and RG62 A/U, are all very small. Although the rather poor sensitivity in some of the measurements precludes a more definite statement, we believe that the values are probably all below 10μa. This equalization of the signal level from an initial ratio of perhaps 100:1 is quite remarkable, and it even seems likely that it can be achieved with fewer than the three training shots used here.

If the two cable conductors are not at the same but at different potentials, the center conductor noise signal is very distinctly affected. This case is covered by Samples 62-7 through 62-10 in Frame 4, Table 6. Besides a definite increase in absolute magnitude above the level of about 1,000μa found in the no-potential data, the polarity of the noise signal is now determined by the sign of the potential gradient, regardless whether the voltage source is connected to the center conductor or to the shield. Thus, the signal polarity is the same for Samples 62-7 and 62-10 and, likewise, for Samples 62-8 and 62-9. In the initial Shot 7, the individual samples differ greatly in their signal magnitude,** but the essential features of their response are clearly evident: in three training shots, the signal level drops about one order of magnitude; the drop is much less sharply pronounced and the final level much higher than in the no-potential series. In Shots 4, 5 and 6, the training effect is completely wiped out by the read, write, and reversal sequence.

The measurements on the shieldless center conductor of the RG62 A/U cable are listed in Frame 2, Table 3. The data on Samples 62-1 and 62-3 qualitatively agree very well with those having the same voltage applied to the center conductor in Frame 4, namely Samples 62-7 and 62-8. Quantitative agreement can hardly be expected in this case, because in the shieldless conductor the return path through the ionized air is not as well defined. Nevertheless, we see some very definite examples for the readout, write, and reversal signals.

With an initial signal of -150μa, the shieldless no-voltage Sample 62-2 differs drastically from the $+750\mu$a signal of its shielded counterpart Sample 62-5 in Frame 3, Table 5 in the same Shot 13. If this result can be confirmed in future experiments, it would mean that the anomalously high RG62 A/U signal cannot be simply ascribed to the air space surrounding the

*The positive polarity of the signal does not agree with the results in the SPRF II series, where all center conductor response signals without applied voltage yielded strong negative signals in the initial shot. Since the known differences in sample configuration are not likely to cause such a marked change, we must leave the resolution of this discrepancy to future studies.

** This difference would be greatly lessened by assuming that the signals contained a superposed hidden contribution of about +1,000μa, i.e., the initial shot signal for the equipotential samples in Frame 3, Table 5.

center conductor but that a more complex interaction involving both the center conductor and the shield must be postulated for its explanation.

In the subsequent Shots 14 and 15, Sample 62-2 exhibits oscillatory response signals almost identical with those of its no-voltage companion Sample RG59-2. After Shot 16 in which no no reading was obtained, the signal is still oscillatory in Shot 17 although the signal bias component has shifted from negative to positive polarity. The value of $-200\mu a$ in Shot 18 must be considered anomalous because there is no known or likely reason why the sample should return to its initial state in this shot.

b. The Noise Signal in the Shield

Unfortunately, the SPRF III series contained only one sample of RG62 A/U cable which was subjected to six shots without a voltage applied to either conductor. This is Sample 62-5 in Frame 3, Table 5. The shield current response of this sample is believed to be fairly representative, although some extraneous interaction may be suspected because of the anomalous responses in Shots 16 and 18.

Two facts about the behavior of the shield current in Sample 62-5 deserve notice. In the initial shot, the signal magnitude is practically equal and opposite to that of the center conductor, and beginning with the second shot, it drops below $-200\mu a$, a level which we established as typical for the RG59 B/U cable shield.

Samples 62-4 and 62-6 show the influence of an applied voltage upon the shield response signal when the center conductor carries the same voltage as the shield. The signal magnitude is increased to a level between $3{,}000\mu a$ and $4{,}000\mu a$, and the polarity is determined by that of the applied voltage. The behavior in all six shots duplicates quite closely that of the RG59 B/U cable Samples 59-4 and 59-6 in the same Frame 3, Table 4. Briefly, there is no evidence for training or memory effects; the signals remain practically constant though the first three repetitive shots, drop to a very low level upon removal of the applied voltage, return to the original magnitude when the voltage is reapplied, and reverse symmetrically upon voltage reversal.

The behavior becomes characteristically different, however, if the voltage is applied to only one conductor at a time, thus creating a potential difference across the cable dielectric. On Sample 62-9 and 62-10 of Frame 4, Table 6, where the voltage is applied to the shield, the current signal is still further increased, namely to a level of $6{,}000\mu a$ or even more. A puzzling discrepancy exists in the behavior of the two samples: while Sample 62-9 follows essentially the trend of no-training and no-memory effects found in the equipotential Samples 62-4 and 62-6 discussed above, there is strong evidence of training in Shot 9, and of memory in Shot 10 of Sample 62-10. The results upon reapplication of the voltage in Shot 11 are reasonable for both samples while the reversals in Shot 12 fall far short of the expected values.

If the voltage is applied to the center conductor, the behavior of the shield signals is different again. In Samples 62-7 and 62-8, the shield current seems to be somehow related to the signal in the center conductor. In the first Shot 7, it is a close mirror image of the center conductor, but rather strong discrepancies develop in further shots. In Sample 62-7, the readings are very consistent in Shots 7, 8, 9 and 11. The difference in signal magnitude in Shot 12 is reasonable because of the removal of the applied voltage, but in Shot 14 the reversed values fall again far short of the expected levels.

In Sample 62-8, the behavior of the shield signal is not quite as consistent. While Shots 7, 10 and 11 exhibit essentially the expected results, the data in Shot 8 and 9 have apparently suffered from extraneous interference; in Shot 12 this sample, too, falls far short of the expected reversal magnitude.

The failure to reach the expected reversal signal in all cases of RG62 A/U samples and also in the two cases of RG59 B/U cable in Frame 4, Table 6 may be more than a puzzling coincidence. In the case of the RG59 B/U sample, we had tentatively surmised that perhaps the batteries were accidentally by-passed in Shot 12. This would in effect mean a repeat of the no-voltage Shot 10 in Shot 12 instead of the planned reversal. This assumption would also fit the behavior of Sample 62-7 where the values of both conductors in Shot 12 are reasonably close to those of Frame 10, but definitely out of line with the expected reversal behavior. Unfortunately, the assumption cannot be applied in Samples 62-8, 62-9 and 62-10. In all three cases the center conductor shows a pronounced reverse effect, while the shield current falls far short of the expected values.

In view of these anomalies, we prefer to disregard the results of the reverse Shot 12 until we can establish the behavior by additional measurements.

We can therefore summarize our findings on the behavior of the RG62 A/U cable in the SPRF III series as follows:

(1) In the absence of a potential gradient between the conductors, the center conductor response signal is about $+1{,}000\mu a$ in the initial shot. Repetitive exposure reduces the signal level drastically so that it practically falls within the response range of the RG59 B/U cable. There are no memory readout, write or reversal effects.

The shield current response is more complicated. If both conductors are on ground potential, the response in the first shot is about equal and opposite to that of the center conductor, i.e., about $-1{,}000\mu a$; in the subsequent repeat shots, it drops to the level below $-200\mu a$ which is also typical of the RG59 B/U shield. If both conductors are at the same positive or negative potential of 268V, the shield current increases to about 3,000 or $4{,}000\mu a$, and its polarity is that of the applied voltage. The magnitude of the signal remains constant without training and memory effects.

(2) If a potential gradient exists between the conductors of the cable, its sign determines uniquely the direction of signal current flow in both conductors, regardless of whether the voltage source is connected to the center conductor or to the shield. The magnitude of the center conductor signal is increased above its level in the no-potential case in the initial shot, and it is reduced in repetitive shots much more gradually. Very strong memory effects occur during the shots in which the potential is removed, reapplied, and reversed.

Unlike the center conductor signal, the shield current response is sensitive to the location of the applied voltage. If the source is connected to the center conductor, the shield current is roughly equal and opposed to the center conductor signal, and its change is magnitude through repetitive shots takes a similar course. The existence of memory effects is unlikely.

If the voltage is applied to the shield, the current signal increases to a level of about $6{,}000\mu a$, thus greatly exceeding the signal of the center conductor. One sample exhibits some training and memory effects, but the other one is clearly free from them.

In all samples with a potential gradient between the conductors, its reversal was not accompanied by the symmetrical reversal of the shield current which is consistently observed in the case where both conductors are kept at the same potential. There is presently no explanation for this anomaly.

c. Results of the Re-Exposure of RG62 A/U Cables Originally Studied in SPRF II

This experiment was conducted in the same manner and for the same purpose as the measurements of previously exposed RG59 B/U cables described above. The results on four

RG62 A/U cables are shown in Frame 1, Table 2. We shall briefly discuss them in the light of the findings just summarized.

Sample 62-16-145 was rechecked in the no-voltage condition in order to duplicate the SPRF II shots. The initial response in Shot 19 of SPRF III continues the decreasing series of values caused by training. In the subsequent Shots 20 through 23, the center conductor values are in very good agreement with the results obtained on Sample 62-13-137 in SPRF II beginning with Shot 3. The shield values of Sample 62-16-145 in these shots are also in very good agreement with the only measurement on Sample 62-13-137 in Shot 10 of SPRF II. In Shot 24, we obtain a write signal of the proper polarity; its magnitude is more than twice as large as that of our straight SPRF III samples.

In the first re-exposure of Sample 62-13-137 in SPRF III, the very large positive response from the center conductor and the corresponding large negative signal from the shield indicate rather conclusively that the condition of exposure was +268V on the center conductor rather than the scheduled no-voltage shot. This fact is further proven by the typical readout and training signals in the two subsequent shots. These are followed in turn by a sequence of write, readout (where the signal went off-scale), and negative write signals. The markedly larger signal in the initial SPRF III Shot 19 is rather strange and cannot be explained.

Sample 62-13-136 was exposed with +268V on the center conductor in SPRF II and in the initial Shot 19 of SPRF III. Its response is a definite write signal. This could simply mean that the training effects of SPRF II have annealed out in the five-month rest period. We hesitate to draw this conclusion, however, because in the light of our new knowledge, the behavior of the sample in the SPRF II series is believed to be inconsistent with the positive voltage presumably applied. The strong negative signal in the first shot of the SPRF II series resembles the no-voltage signal of Sample 62-16-145 and cannot be reconciled with a positive applied voltage. Quite possibly, however, the voltage was finally applied to the sample in Shot 4 of SPRF II, although the response should perhaps be somewhat larger for a true write signal. We have therefore no conclusive evidence from this sample on the question of recovery from training. In its SPRF III exposures, all signals are in keeping with our memory and training rules and their magnitude agrees very closely with that of the two other samples previously described.

Sample 62-22-148 had been exposed with an applied voltage of +536V in three shots of SPRF III in which it showed proper training behavior followed by a very large readout signal in the subsequent no-voltage shot. Three additional no-voltage shots in SPRF III begin with a relatively strong negative signal which is drastically reduced to a level closely approaching the signals of Sample 62-16-145 in the same shots. The positive and negative write signals in Shots 22 and 24 indicate a close proportionality of the signal magnitude to the applied voltage.

In spite of the questions and uncertainties about the re-exposed samples, their behavior in the SPRF III series conforms in almost every deatil with the general rules we derived from our new measurements, allowing of course for the difference in signal magnitude caused by the different sample configuration. The only notable exception is the negative polarity of the no-voltage center conductor signal of Sample 62-16-145, which is in clear contradiction to our positive signals in the initial exposure of equipotential samples. The negative response of Sample 62-22-148 is in a different category because it could be due to the strong preceding negative readout signal.

The Noise Signal of the Multi-Conductor Ribbon Cable

This cable consists of eight copper conductors with a cross-section of .062" x .0027", which are molded with a center-to-center spacing of .125" between two layers of mylar ribbon 1.125" x .005".

One sample of this cable, Nr. MCC-1, was exposed in Frame 7; the results are given in Table 10. The two conductors near one edge of the ribbon (Nr. 1 and Nr.2) were observed without applied voltage, while conductor 5 and 8 carried the usual positive and negative voltage of 268V.

These conductors yielded signals of +4,000μa and −2,000μa in the first Shot 25 and exhibited the regular training behavior and readout in Shots 26, 27 and 28. In the two final Shots 29 and 30, both samples go through a write and voltage reverse sequence which for Conductor 8 is somewhat different from our normal schedule: after the no-voltage Shot 28, a positive voltage was applied instead of the usual repetition of the original negative voltage, thereby placing both Conductors 8 and 5 at the same potential in Shot 29 and, upon reversal, in Shot 30. The signal magnitude of the conductors with applied voltage is comparable to that of the RG62 A/U center conductor in the initial Shot 25. While the signal is drastically reduced in the second shot, there is no appreciable further training ir the third. The no-voltage readout signals are about half as large as those in the preceding voltage shot, and the subsequent write signals have exactly the same absolute value with the proper polarity. In the reversal shot the expected doubling of the signal is observed in Conductor 8 and even exceeded in Conductor 5.

The response of the no-voltage Conductors 1 and 2 is definitely affected by parasitic interaction, and in all probability the donor for both is Conductor 5. Their true response is probably observed in Shot 28, where all samples contained in Frame 7 were tested without applied voltage. Their signals in this shot consist of small oscillations similar to those we observed in several measurements on shieldless conductors in Frame 2.

The strong resemblance between the response of the mylar multi-conductor cable and that of RG62 A/U was entirely unexpected. It proves that strong noise signals can be generated without an air space around the conductors. The difference in the response of RG59 B/U and RG62 A/U cables can no longer be ascribed simply to the open construction of the latter but other possibilities must be considered.

The Noise Signal in a Single Conductor of WD-1/TT Cable

The behavior of the WD-1/TT Electrical Telephone Cable in the SPRF II series was characterized by two points of difference from the RG59 B/U and RG62 A/U cables: its response signal was always positive and it failed to exhibit any training effect in repetitive shots. Three samples of single WD-1/TT conductors were included for comparison with the single center conductors of the other cables in Frame 2 of the SPRF III experiment.

Unfortunately, the results are very strongly affected by parasitic interaction and cannot be accepted as representative for the WD-1/TT cable. The only value free of this effect is the no-voltage signal of Sample WD-1-3 in Shot 16. Taken by itself, however, this value of +50μa does not yield much information because the effect of the previous shots with respect to training and memory is unknown. The results are included here for the record and as an additional example of the parasitic interaction between adjacent cables.

2. DC AND AC MEASURING METHODS AND SOME PRELIMINARY RESULTS

DC Measurements of Resistors

In an attempt to reduce or eliminate the strong signals found in cables carrying an applied voltage, an experiment was included in the SPRF III series in which the center conductor was surrounded by a guard shield at the same potential. This experiment was carried out in two different forms in Frame 7, Tables 8 and 9. The circuit diagrams are shown in Appendix B.

In one form, the test object, a precision carbon film resistor of 100 kohm was connected to the center conductors of two lengths of RG59 B/U cable, Sample 59-17 and 59-18; a voltage of +268V was applied to one of the center conductors and a voltage of −268V to the other one, thus causing a circulating current of 5.4 ma to flow continuously. By means of separate batteries, the shields were placed at an off-ground potential equal to that of the respective center conductors, except in Shot 26 where the shield potential was only one half as high.

In the other form of the measurement, a tri-coaxial cable type 21-527 was used, which consists of a regular RG59 B/U cable surrounded by an additional shield and jacket. In this case (Sample 21-527-2), the 100 kohm resistor was connected between the center conductor and the outer shield. The inner shield served as guard for the center conductor and both were independently kept at +268V, while the outer shield was at ground potential. For the purpose of direct comparison, a second sample, Nr. 21-527-1 was connected in the same way except that the 100 kohm resistor was left out and the cable conductors were electrically open at the exposed end.

It had been the intention to measure the temporary current increase or decrease in the circuit containing the resistors in order to determine the change in resistance, if any. As we pointed out in our discussion of the noise signals in these cables, the measurements with the RG59 B/U cable were disturbed by the differentiation of the strong shield currents. If we subtract the oscillatory component from the total observed signal, we obtain a net signal which is negative in both legs of the circuit, while a change in resistance would require signals of opposite signs in both legs. The observed signal, therefore, cannot be related to a change in resistance.

In a more positive way, we can say that the largest signal observed in all the center conductors in any shot did not exceed a peak-to-peak value of $70\mu a$. If this signal were entirely due to a change in resistance, it would constitute only a 1.4% change of the quiescent current of 5.4 ma, and we can therefore state that the actual change was less, and most likely much less than 1.4%.

In the measurements with the tri-coaxial cable, we do not have the problem with oscillatory responses. Although we lost some readings, we find that the center conductor signals stay below $20\mu a$ in all observed cases. Furthermore, these signals are exactly alike in both cables regardless of the difference between the open circuit and the closed circuit which in this case carried a current of 2.7 ma. We can therefore state with some assurance that no current signal was observed which would have indicated a resistance change. Since the sensitivity in this case was better than $5\mu a$, we conclude that the resistance change was less than .2%.

AC Measurements of Impedance Changes

The measurement of temporary changes in resistance and reactance during the radiation pulse has been a problem of long standing. Our attempt to contribute to its solution is based on the measurement of phase and amplitude of a suitable RF carrier before and during the radiation burst. The phase measurement is made by displaying the current and voltage of the RF signal at a selected point in time close to the peak of the radiation pulse. In order to achieve sufficient resolution, the signal must be expanded so that only one or two cycles appear on the scope. The amplitude is measured over a longer period of time, namely approximately five times the duration of the radiation pulse. Examples of the traces are shown in Fig. 1.

The actual measurements were made at or near frequencies for which the cable length was a quarter wavelength (1 - 2 mc/s) in order to achieve maximum current sensitivity. The lumped parameters of the exposed parts and the cable are referred back to the cable input where they are monitored. The derivation of the impedance change in terms of the amplitude and phase shift measurements is given in Appendix C.

The two resistors at the input end of the cable are chosen to match together its characteristic impedance; the current measuring resistor was kept as small as possible in order to preserve the constant-voltage characteristics of the source. The RF voltage is coupled into the test circuit by a transformer, this permitting the oscillator, the cable, and the oscilloscope to be grounded.

An additional feature of the circuit is the insertion of a high-pass filter with a cutoff frequency of 50 kc/s. The purpose of this filter is the suppression of the ordinary noise signals which have an equivalent frequency of about 10 or 20 kc/s depending on whether they are single pulses or differentiated pulse signals.

In the actual measurements, the oscilloscope sweep rate for the phase observation was set at 0.1 μsec/cm, thus accommodating about two cycles of the voltage and current of the test frequency. The oscilloscope for the phase measurement was triggered with a preset delay of 230 μsec from the timing signal of the reactor in order to coincide with the peak of the radiation pulse. The amplitude signal was triggered without delay and its sweep rate was 50 μsec/cm, thus allowing a much longer observation period.

Measurements were attempted on cables with various terminations as listed in Fig. 1. The resolution of the measurements was established by calibration and was found to be quite poor for the intended purpose, namely about ±15% for the resistance values and about ±20% or even ±40% for the capacitance changes. In addition, the actual measurements suffered from extraneous noise further reducing the sensitivity.

We were therefore unable to observe any deviation of the observed characteristics during the radiation pulse from those established beforehand. It is hoped, however, that the method can be refined sufficiently to yield useful results in future experiments.

3. RF CARRIER MODULATION

The first experiments on RF transmission through cables exposed to nuclear radiation pulses were conducted in the SPRF II series.[3] These measurements had been made with an input signal level of about 1 volt. While no change in amplitude occurred in the signal transmitted through the RG59 B/U cable, an attenuation of almost 20% was observed in the RG62A/U cable during the radiation pulse.

In the SPRF III series, these measurements were extended to lower signal levels (35 to 430 millivolts) in order to check whether an effect in the RG59 B/U cable would become observable at higher sensitivity settings of the oscilloscope and also in order to determine whether the attenuation in the RG62 A/U cable depends upon the signal level.

Since the ordinary cable noise signals superimpose themselves upon the envelope of the RF signal, they can obviously become competitive in magnitude and drive the carrier signal off the scope screen when high sensitivity is required. It was therefore necessary to separate the noise signal from the RF carrier. Since the noise signal contains hardly any components exceeding a frequency of 20 kc/s, while the RF carrier frequency used is higher than 1 mc/s, the separation was attempted by insertion of a high-pass filter having a cutoff frequency of 50 kc/s. Comparison measurements with and without filter were made in order to determine the efficacy of this method.

The measurements were limited to one sample of each of the two cable types RG59 B/U and RG62 A/U, which were exposed together with the samples contained in Frame 7 in Shots 25 through 30. The samples were 100 ft. long; their center portion of approximately 20 ft. in length was wound into a flat spiral and mounted for maximum exposure as close to the reactor surface as possible; an additional total of 30 ft. of their length was inside the reactor room forming straight leads to and from the spiral portion. Each cable was terminated at the input and output end by a resistor equal to its characteristic impedance, from which the transmitted signal was monitored. The carrier frequency was 1.35 mc/s for the RG59 B/U cable and 1.58 mc/s for RG62 A/U.

The oscilloscope traces of all measurements and the data obtained are shown in Fig. 2. The top trace of each photograph respresents the RF signal transmitted through the RG59 B/U cable and the bottom trace is the output of the RG62 A/U sample.

In all six shots, the amplitude of the signal from RG59 B/U remains unchanged throughout the period of the radiation pulse, although superposed cable noise signals occur as expected in Shots 25 and 28 in the absence of the high-pass filter. By comparison with the traces in Shots 26 and 27 in which the RF amplitude and the scope sensitivity were the same as in Shots 25 and 28, respectively, the complete suppression of the noise signal by the insertion of the filter is easily recognizable.

The effect of the filter is perhaps even more impressive in the measurements of the RG62 A/U cable. In the two shots without filter the noise signal is very pronounced; in the initial Shot 25, it drives the RF carrier signal off the scope screen, and even in the fourth exposure, it still exceeds 100μa. In the intermediate Shots 26 and 27, however, there is no indication of noise superposition with the filter inserted in the circuit, and the benefit with respect to the sensitivity of the attenuation measurement is evident.

The amount of modulation observed in the RF signal transmitted through the RG62 A/U cable varies between −13 and −18 per cent of its peak-to-peak amplitude. There is no apparent relationship between the attenuation and the signal amplitude; the lowest and the highest value occur in Shots 29 and 30 where the RF amplitude was practically the same. As much as can be determined from the available results, there is also no change in the amount of modulation due to training effects.

These results agree very well with the observations in the SPRF II experiments, and we conclude that the modulation of the RF signal in the RG62 A/U cable is not directly relatable to its ordinary noise response; we believe that instead it is caused by a temporary change in transmission characteristics of the cable. A possible mechanism for such a change may be a drastic increase in the effective cable capacitance by the ionization of the air surrounding the center conductor during the radiation pulse.

We had hoped to measure this capacitance change directly by the phase and amplitude observations described above. This attempt failed partially because the effect is much smaller in the straight cable configuration which we tried to use for this purpose. A repetition of the measurement will therefore be attempted with the flat spiral sample in a future experiment.

CONCLUSIONS

The experiments of the SPRF III series described here have significantly increased our knowledge and understanding of the characteristic response of two types of coaxial RF cables, namely RG59 B/U and RG62 A/U, when exposed to nuclear radiation pulses under a variety of conditions. The following findings are believed to be particularly important:

1. The noise signals generated in the above cables are not single-valued characteristics but rather complex functions of: the applied voltage and potential gradient; the number of repetitive shots under unchanged conditions; and the direction and magnitude of voltage changes from one condition to another in successive shots. In repetitive exposures the signal magnitude declines by "training processes," and in successive shots under changed voltage conditions the signals reflect storage or memory effects in the cable. In the initial exposure without an applied voltage the signal levels of the two cable types differ by about two orders

of magnitude. By proper training they can be brought to a common level of less than 5μa; this training effect will apparently persist through long rest periods, but an exposure under changed conditions will destroy it immediately.

2. The cable shield signals are generally larger than those from the center conductor, probably because the shield is in much more intimate contact with the ionized environment. Application of a voltage to the shield enhances this effect greatly and can easily cause signal currents of several milliamperes. These in turn can introduce strong oscillatory signals into the center conductor, since the cable conductors with their distributed capacity and their attached measuring resistors form a differentiating network. Strong shield currents may also inject parasitic currents into any conductor in the vicinity, and even these may still be strong enough to cause the appearance of differentiated signals. Limited experiments with a tri-coaxial cable indicate that shield currents can be almost completely suppressed by keeping the additional outer shield at ground potential.

3. DC measurements of small temporary changes of a rather large quiescent current (typically 5μa in 5,000μa) can be made with good reliability, thus permitting measurements of resistance changes during the radiation pulse with remarkable accuracy. The measurement of temporary impedance changes by RF phase and amplitude observations requires further refinements.

4. RF transmission experiments confirm the earlier finding that the carrier signal is transmitted without a measurable effect of the radiation pulse through the RG59 B/U cable, while it suffers a temporary attenuation of almost 20% when passing through RG62 A/U. Tentatively, this difference is ascribed to air ionization inside the cable.

5. The following rules have been established for keeping the noise signals from cables used in the measurement of transient effects of nuclear radiation pulses to an absolute minimum:

a. Use the shortest cable run possible inside the reactor room.

b. Reduce the voltage for the measurement as far as possible.

c. If a high voltage is required, use a tri-coaxial cable with the outer shield grounded.

d. Keep all cables spaced uniformly apart and avoid inadvertent leakage paths through metal strips, holders, plates, etc.

e. Keep a log of the cable history in terms of training shots; use cable only under conditions for which it was trained; if a new condition is called for, pre-expose the cable without the test object once or several times.

f. When using a compensation technique involving the subtraction of a dummy cable signal, train and pre-test both cables before the intended measurement; monitor the dummy cable signal during the measurement.

g. Provide low resistance ground connection for all outer cable shields.

h. Whenever possible, use ac measurements and suppress the noise signal by filtering.

ACKNOWLEDGMENTS

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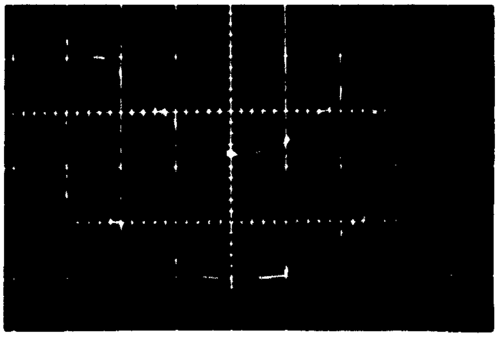
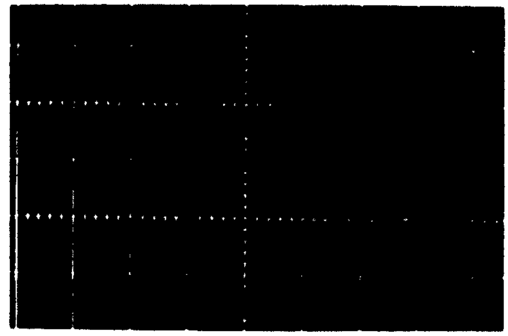
4. K. Ikrath and R. Constantine, "Nuclear Pulse Effects in Cables," Conference Paper AIEE Summer General Meeting, Denver, Colorado, June 1962.

Before Irradiation

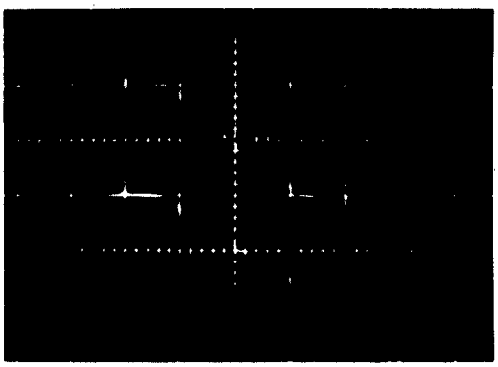


R.F. Current Amplitude: 1.08 ma p-p
Sweep Rate: .1μsec/div

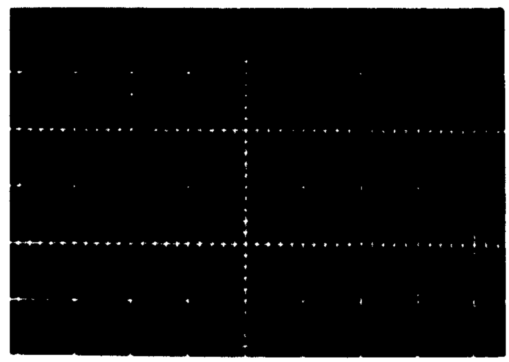


R.F. Current Amplitude: 1.08 ma p-p
Sweep Rate: 50 μsec/div

During Irradiation



R.F. Current Amplitude and Phase for
Determining Dynamic Impedance Changes

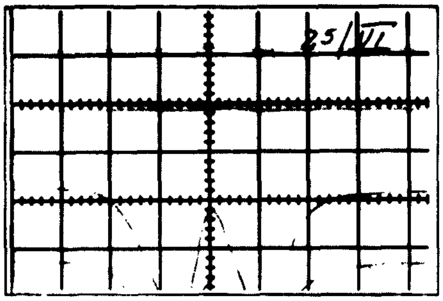


R.F. Current Amplitude: 1.08 ma p-p
Sweep Rate: 50μsec/div

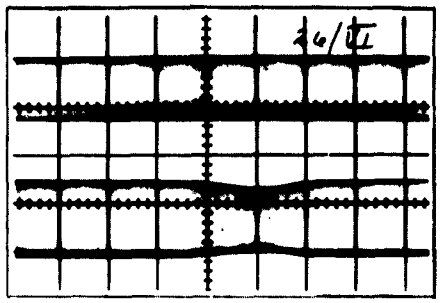
CABLE TYPE	TERMINATION	FREQ mc/s	PART CHANGE RESOLUTION
RG-59 B/U	Open 75Ω * 500 $\mu\mu$f	1.35	< ±15% < 200 $\mu\mu$f
RG-62 A/U	Open 93Ω 500 $\mu\mu$f	1.90	< ±15% < 100 $\mu\mu$f
TV	Open 300Ω	1.52	<±15%

* The above traces were taken on a 75Ω Sample attached to RG-59 B/U.

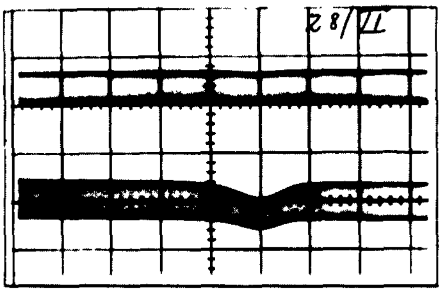
Fig. 1 Comparison of R.F. Current Amplitude and Phase Before and During Irradiation for Determining Dynamic Impedance Changes.



WITHOUT H-P FILTER



WITH H-P FILTER



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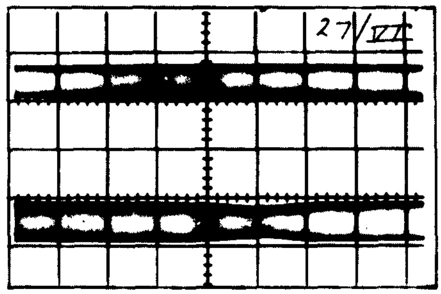

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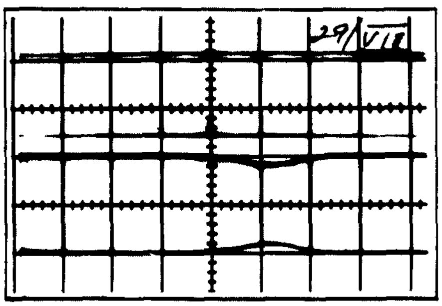

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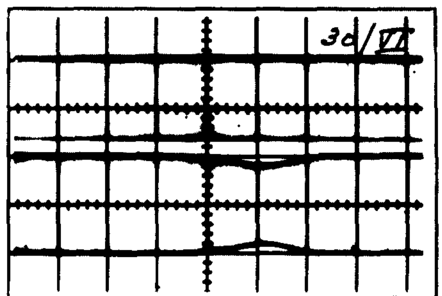


WITH H-P FILTER → ← 50 μsec

	SHOT NR.	25	26	27	28	29	30
RG-59B/U	Δ R.F. Amp. (%)	0	0	0	0	0	0
UPPER TRACE	Noise W/O Filter (μs)	67			34		
1.35 MC/S	W Filter		0	0		0	0
RG-62A/U	Δ R.F. Amp. (%)	off-scale	16	18	18	13	18
LOWER TRACE	Noise W/O Filter (μs)	>+1000			107		
1.58 MC/S	W Filter		0	0		0	0
R.F. Amp (mv p-p)		~70		~40		~400	

FIG. 2 COMPARISON OF THE RADIATION EFFECTS ON R.F. TRANSMISSION THROUGH RG-59B/U AND RG-62A/U COAXIAL CABLES

TABLE 1

RG59 B/U Cable. Re-exposure of Samples from SPRF II (Frame 1)

SAMPLE NR.	APPLIED VOLTAGE		ORDER NUMBER OF EXPOSURE IN SPRF II										SHOT NUMBER IN SPRF III					
			1	2	3	4	5	6	7	8	9	10	19	20	21	22	23	24
59		+268														+300		
−13	Cen	0	−100	−50	−25	−10	−10	−5	−3) +3)	−15	−5) +5)	−20) +20)	−5) +40)	−10) +10)	−5) +5)		−300	
−138		−268																−300
	Sh	0										−230	−190	−220	−280	−650	+60	+100
59		+268																+280
−16	Cen	0	−80	−70	→								−10) +45)	−10 +5)	−10) +5)		+230	
−146		−268														−260		
	Sh	0	+300	+160	→								−360	−170	−220	−150) +125)	−360	−450
59		+268	−50	+380	→								+140	+85	−40) +35)			+200
−7	Cen	0														−200	−80	
−125		−268																
	Sh	0													−350	−300) +80)	−220) +40)	−550
59		+268	−85) +45)	+30	→								+240	+170	+60			
−5	Cen	0														−400	−140	
−115		−268																−500
	Sh	0													−350	−280) +140)	−120) +40)	−100) +100)
59		+268	−50) +10)	−15	N.R.	+25) −5)	+15	+5	+15	→			+330			+500		
−13	Cen	0												−225	−20) +20)		−260	
−137		−268																−350
	Sh	0													−280	−750	+100	−100) +100)

Tabulated Values: Peak Current in Microamperes

TABLE 2

RG62 A/U Cable. Re-exposure of Samples from SPRF II (Frame 1, Cont.)

SAMPLE NR.	APPLIED VOLTAGE		ORDER NUMBER OF EXPOSURE IN SPRF II										SHOT NUMBER IN SPRF III					
			1	2	3	4	5	6	7	8	9	10	19	20	21	22	23	24
		+268																+5,500
62-16	Cen	0	–6,250	–1,200	→								–500	+40	+40	N.R.	+100	
		–268																
–145	Sh	0	+6,000	+850	→								N.R.	–200	–280	N.R.	–350	–6,000
		+268														+5,500		
62-13	Cen	0	–1,200	–1,400	+50	N.R.	+100	+35	+35	+75	+25	+50	+8,000*	–4,500	<–500		–O.S.	
		–268																–5,000
–137	Sh	0										–250	–6,750	+4,000	<–500) <+500)	–5,500	+O.S.	+5,000
		+268	–5,500	+500) –100)	+200	+1,750	+200	–20	→				+4,400			N.R.		
62-13	Cen	0												–5,000	–500		–O.S.	
		–268																–5,500
–136	Sh	0													<–500) <+500)	–6,000	+O.S.	+5,000
		+536	+4,000	+2,800	+900											+10,000		
62-22	Cen	0				–15,000	→						–1,500	–40) +50)	+85		–O.S.	
		–536																–9,000
–148	Sh	0												–40) +50)	–200	–9,000	+O.S.	+8,000

*This Sample believed to have carried an applied voltage of +268V instead of 0V in this exposure. (See text)

Tabulated Values: Peak Current in Microamperes.

TABLE 8

RG59 B/U and RG62 A/U, Shieldless, and WD-1/TT Single Wire (Frame 2)

SAMPLE NR.	APPLIED VOLTAGE	SHOT NUMBER					
		13	14	15	16	17	18
59-1	+268	−35) +35)	−15) +5)	−10) +40)		−90) +20)	
	0				+150) −15)		
	−268						−50
59-2	0	−80) +10)	−25) +10)	−20) +10)	+100) −10)	−110) +15)	−40
59-3	+268						−45) +15)
	0				−20) +35)		
	−268	−60	−10) +25)	−50		−20	
62-1	+268	> +600	+150	+50) +30) +70)		+600	
	0				−500		
	−268						<−50) 0) <−50)
62-2	0	−150	−45) +5)	−35) +15)	N.R.	−25) +50)	−200
62-3	+268						+1,900
	0				N.R.		
	−268	−1,300	−400	−140		−1,100	
WD-1-1	+268	+140	+70	<−5) +55)		+80	
	0				N.R.		
	−268						−140
WD-1-2	0	+175	+80	−20) +20)	N.R.	+120	−220) < +20)
WD-1-3	+268						−200
	0				+50		
	−268	+200	+50	+200) −20)		+250	

Tabulated Values: Peak Current in Microamperes

TABLE 4

RG59 B/U Cable. Conductors at Equal Potential (Frame 3)

SAMPLE NR.	APPLIED VOLTAGE		SHOT NUMBER					
			13	14	15	16	17	18
59-4	Cen	+268	+75) −75)	+75) −80)	+80) −80)		+75) −80)	
		0				< ±10		
		−268						−80) +85)
	Sh	+268	+3,500	+3,300	+3,400		+3,000	
		0				<−500		
		−268						−3,500
59-5	Cen	+268						
		0	+15) −20)	+15) −20)	+15) −15)	<−5) <+5)	+20) −175)	−20) +20)
		−268						
	Sh	+268						
		0	>+600	+700	+750	−50	+675	−750
		−268						
59-6	Cen	+268						+110) −110)
		0				<+10		
		−268	−110) +110)	−100) +110)	−110) +110)		−100) +110)	
	Sh	+268						+4,750
		0				<−500		
		−268	−4,000	−4,200	−4,400		−4,500	

Tabulated Values: Peak Current in Microamperes.

TABLE 5

RG 62 A/U Cable. Conductors at Equal Potential (Frame 3 Cont.)

SAMPLE NR.	APPLIED VOLTAGE		SHOT NUMBER 13	14	15	16	17	18
62-4	Cen	+268	+1,000	+100) <−100)	+80) −70)		+100) −65)	
	Cen	0				<−50		
	Cen	−268						−100) +100)
	Sh	+268	+3,000	+3,300	+3,500		+3,250	
	Sh	0				<−50		
	Sh	−268						−3,000
62-5	Cen	+268						
	Cen	0	+750	<−100	<−5	−5	<−5) <+5)	<±5
	Cen	−268						
	Sh	+268						
	Sh	0	−1,000	−150	−170	−80) +10)	−165	+20) −80) +30)
	Sh	−268						
62-6	Cen	+268						+120) −80)
	Cen	0				<±500		
	Cen	−268	+1,000	−100) +100)	−110) +80)		−100) +60)	
	Sh	+268						+3,500
	Sh	0				<±1,000		
	Sh	−268	−4,500	−4,000	−3,800		−3,750	

Tabulated Values: Peak Current in Microamperes.

TABLE 6

RG59 B/U and RG62 A/U Cable. Potential Applied to Either Conductor (Frame 4)

SAMPLE NR.	APPLIED VOLTAGE		SHOT NUMBER 7	8	9	10	11	12
59-7	Cen	+268	+10	+5	<−5		+20	
		0				−20		
		−268						−30
	Sh	0	−150	−150	−150	−50	−180	N.R.
59-8		+268						+30
	Cen	0				+10		
		−268	N.R.	−10	<−5		−15	
	Sh	0	−1,000	−1,050	−1,000	<−100	−1,000	+100
59-9	Cen	0	N.R.	+10) −35)	+15) −25)	+35	+5) −35)	+35
		+268	+5,500	+5,400	+5,500		>+6,000	
	Sh	0				<−500		
		−268						−500
59-10	Cen	0	−40) +5)	−15) +10)	−15) +10)	−15	<−5) +25)	−35
		+268						<+500
	Sh	0				<+500		
		−268	−O.S.	−4,200	−4,000		−4,000	
62-7		+268	+2,600	+1,600	+350		+2,300	
	Cen	0				>−1,500		
		−268						−1,000
	Sh	0	−2,150	−1,500	−300	+180	−2,300	+350
62-8		+268						+2,500
	Cen	0				+500		
		−268	−1,300	−1,000	−75		−450	
	Sh	0	+1,200	−100) <+100)	<−100) <+100)	<−50	+1,700	−200
62-9	Cen	0	−1,200	−100	−80	>+400	>−500	+1,000
		+268	>+6,000	+5,000	+5,200		+6,500	
	Sh	0				<−500		
		−268						−1,000
62-10	Cen	0	>+1,500	+1,300	+200	−1,500	+2,300	−3,200
		+268						+1,000
	Sh	0				>+2,000		
		−268	−O.S.	−6,000	−600		−8,500	

Tabulated Values: Peak Current in Microamperes.

TABLE 7

RG59 B/U Effect of Pre-Irradiation with +1.8kv Applied to Center Conductor (Frame 5)

SAMPLE NR.	APPLIED VOLTAGE		SHOT NUMBER IN SPRF III						SHOT NUMBER IN SPRF IIIA				
			7	8	9	10	11	12	1	2	3	4	5
59-11	Cen	+268	−15	−10	< ±5		+10		+10	< +5		+25	
		0				−20					−20		
		−268						−10					−25
	Sh	0	< +50	−50) +50)	<−50	< ±50	<−50	< ±50	−150	−100	−125	−150	−125
59-12	Cen	+268					+5					+20**	
		0	−15	<−5	<−5	<−5			<−5	−1.5**	+1**		
		−268						−10					−20
	Sh	0	< ±50	<−50	< ±50	< ±50	−50	< ±50	−100	−100	−100	−150	−100
59-13	Cen	+268						+15					+35
		0				< +5					+15		
		−268	< ±5	<−5	−5		−5		−20	−5		−15	
	Sh	0	< ±50	<−50	< ±50	< +50	−50	< ±50	−100	−110	−155	−105	−150
		+268	−20	< +5	< +5		+20						+35
59-20*	Cen	0				−10) +5)					+20		
		−268						−110) +100)	−15	−5		−20	
	Sh	0	−50	−50	−75) +50)	−100) +50)	−50) +50)	−100) < +50)	−100	−100	−150	−100	−175

*Sample Nr. 59-20 was exposed in Shots 19 through 24 of Frame 1 (Tables 1 and 2).

**Increased sensitivity by use of pre-amplifier.

Tabulated Values: Peak Current in Microamperes.

TABLE 8

RG59 B/U Cables. Carbon Film Resistor 100 kohm Attached to Center Conductors (Frame 7)

SAMPLE NR.	APPLIED VOLTAGE		SHOT NUMBER IN SPRF III					
			25	26	27	28	29	30
59-17	Cen	+268	+6) −40)	+10) −10)	+13) −10)		+35) −35)	
		0				−7		
		−268						−40) +30)
	Sh	+268	+6,350		+4,000		+7,800	
		+134		+3,340				
		0				−170		
		−268						−8,000
59-18	Cen	+268						+20) −20)
		0				−2		
		−268	−50) +12)	−30) +4)	−20) +8)		−15) +20)	
	Sh	+268						+7,000
		0				−100		
		−134		−4,280				
		−268	−6,800		−3,800		−7,000	

Tabulated Values: Peak Current in Microamperes.

TABLE 9

Tri-Coaxial Cable 21-527. Open Cable and Cable with Carbon Film Resistor 100 kohm Attached between Center Conductor and Outer Shield (Frame 7 Cont.)

SAMPLE NR.	APPLIED VOLTAGE		SHOT NUMBER IN SPRF III					
			25	26	27	28	29	30
	Cen	+268	N.R.	−10	+10) −5)		<−10	
21	Cen					−10		
	Cen	−268						−5) +5)
−527	Sh I	+268	<+100	+50			+50	
	Sh I	0			0*	+15		
−2	Sh I	−268						−50
	Sh II	0	N.R.	−150	−100	−50	−200	+200
	Cen	+268	N.R.	−10	+15) <−5)		<−10	
21	Cen	0				−10		
	Cen	−268						<±5
−527	Sh I	+268	+100	+85			+60	
	Sh I	0			0*	+20		
−1	Sh I	−268						−70
	Sh II	0	N.R.	+200	−500	−50	−800	+700

*Floating Ground

Tabulated Values: Peak Current in Microamperes

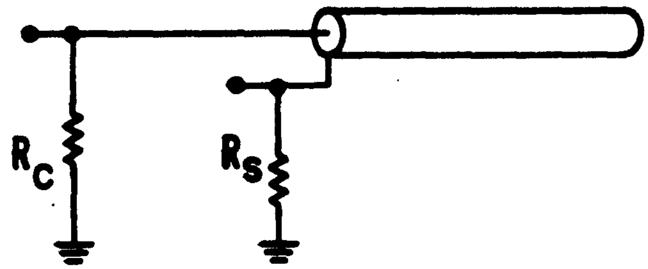
TABLE 10

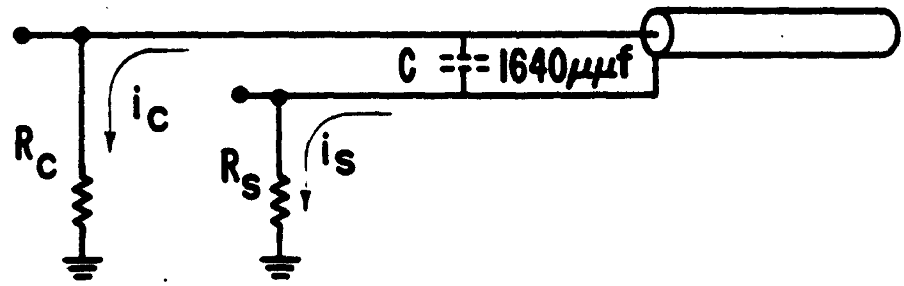
Multi-Conductor Mylar Ribbon Cable (Frame 7 Cont.)

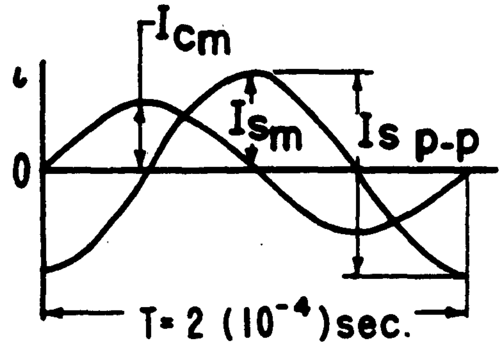
SAMPLE NR.	APPLIED VOLTAGE		SHOT NUMBER IN SPRF III					
			25	26	27	28	29	30
MCC-1	Cond I	0	−150	+10) −180)	−190	−10) +20)	−140	+140
	Cond II	0	−300	−140	−120	<−20) +40)	−220	+700
	Cond V	+268	+4,000	+800	+1,000		+600	
		0				−600		
		−268						−1,500
	Cond VIII	+268					+400	
		0				+400		
		−268	−2,600	−800	−700			−800

Tabulated Values: Peak Current in Microamperes.

APPENDIX A







$$i_C = CR_S \frac{d}{dt} i_S = CR_S I_{S_m} \frac{d}{dt}(-\mathrm{COS}\ \omega t) = \omega C R_S I_{S_m} (\mathrm{SIN}\ \omega t)$$

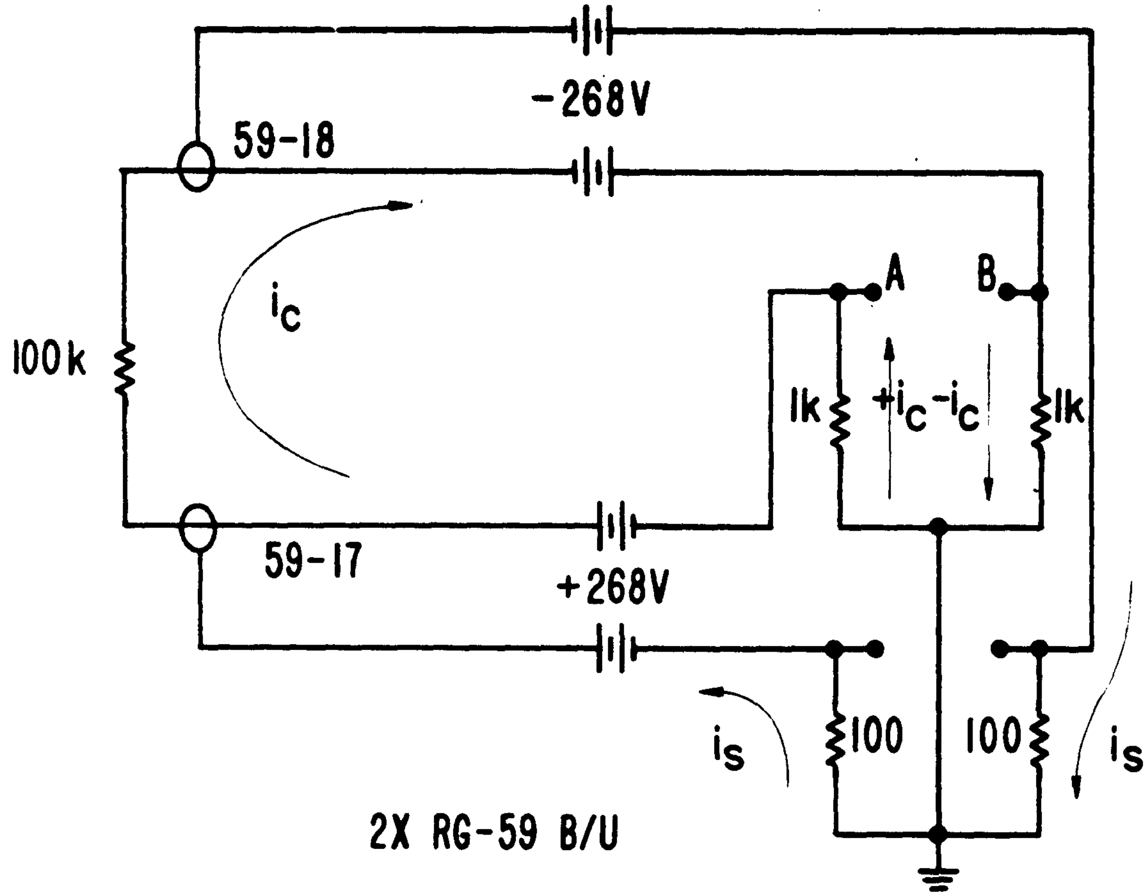
$$\frac{I_{cm}}{I_{sm}} = \omega C R_S = \frac{2(3.14)(1640\times 10^{-12})\, R_S}{2(10^{-4})}$$

= 0.51% FOR R_S = 100 OHM

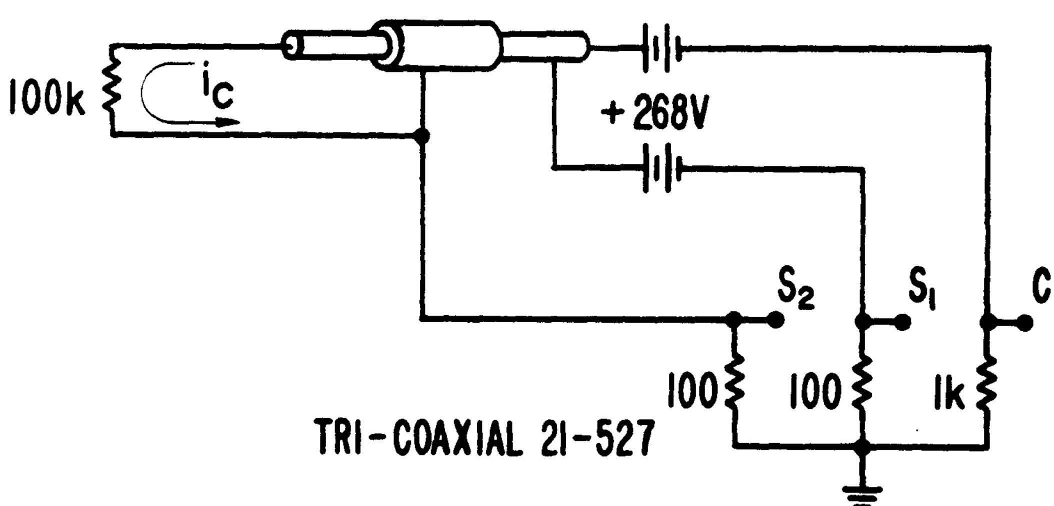
= 5.1% FOR R_S =1000 OHM

CENTER CONDUCTOR NOISE SIGNAL
CAUSED BY DIFFERENTIATION OF SHIELD CURRENT

APPENDIX B



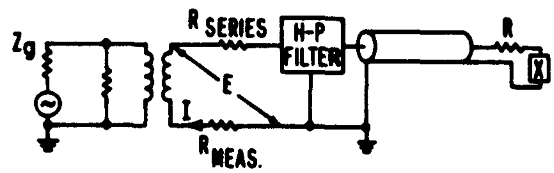
2X RG-59 B/U



TRI-COAXIAL 21-527

GUARD CIRCUIT FOR RESISTANCE MEASUREMENTS

APPENDIX C



BEFORE IRRADIATION:

$$E = I_1 (R + jX); \quad \tan \theta_1 = \frac{X}{R}$$

$$\left|\frac{E}{I_1}\right|^2 = R^2 + X^2$$

DURING IRRADIATION:

$$\left|\frac{E}{I_2}\right|^2 = (R + \Delta R)^2 + (X + \Delta X)^2; \quad \tan \theta_2 = \frac{X + \Delta X}{R + \Delta R} \quad \text{WHERE } \theta_2 = \theta_1 + \Delta\theta$$

$$\Delta R = \frac{\left|\frac{E}{I_2}\right|}{\sqrt{1 + \tan^2 \theta_2}} - R$$

$$\Delta X = \tan \theta_2 (R + \Delta R) - X = \frac{\tan \theta_2 \left|\frac{E}{I_2}\right|}{\sqrt{1 + \tan^2 \theta_2}} - X$$

In this derivation, the effects in the cable or any part affixed to the cable end due to the radiation burst have been calculated at the cable input. These calculated impedance changes ΔR and ΔX at the cable input must be transformed over the electrical cable length to the output where the effects actually take place. A Smith chart can be used to transform these impedance effects to the cable output.

If the cable and any part affixed to the cable end constitute a quarter wave length of the test frequency before irradiation, $X = 0$ and $\left|\frac{E}{I_1}\right|^2 = R^2$.

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The electrical noise signals generated in the individual conductors of coaxial and other cables by incident nuclear radiation pulses were studied as a function of the applied voltage and the exposure history. Training processes were found to reduce the response signals in repetitive exposures, while storage or memory effects can cause strong readout signals if the applied voltage is changed in successive shots. Oscillatory signals in the center conductor were found to be caused by differentiation of the unexpectedly large shield current pulses. The latter can also inject parasitic leakage currents into other conductors nearby. An RF signal transmitted through RG62 A/U cable suffers a temporary attenuation of almost 20 percent, while it passes through RG59 B/U cable unaffected. Methods for the dynamic measurement of noise, resistance, attenuation and impedance are described, and definite rules are given for minimizing noise signals from cables used in nuclear pulse radiation measurements.

1. Radiation effects--Gamma and neutron pulses
2. Coaxial cables--Noise transients, training, memory, leakage effects
3. RF modulation--Transient impedance change
4. Dynamic measurement--Noise, resistance, attenuation, impedance

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